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(71) Applicant *(for all designated States except US):* THE TECHNOLOGY PARTNERSHIP LIMITED [GB/GB]; Melbourn Science Park, Cambridge Road, Melbourn, Royston, Hertfordshire SG8 6EE (GB).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)* : GREEN, Ross, Martin [GB/GB]; 37 Bishops Road, Trumpington, Cambridge CB2 2NQ (GB).

(74) Agent: BRUNNER, Michael, John; Gill Jennings & Every, Broadgate House, 7 Eldon Street, London EC2M 7LH (GB).

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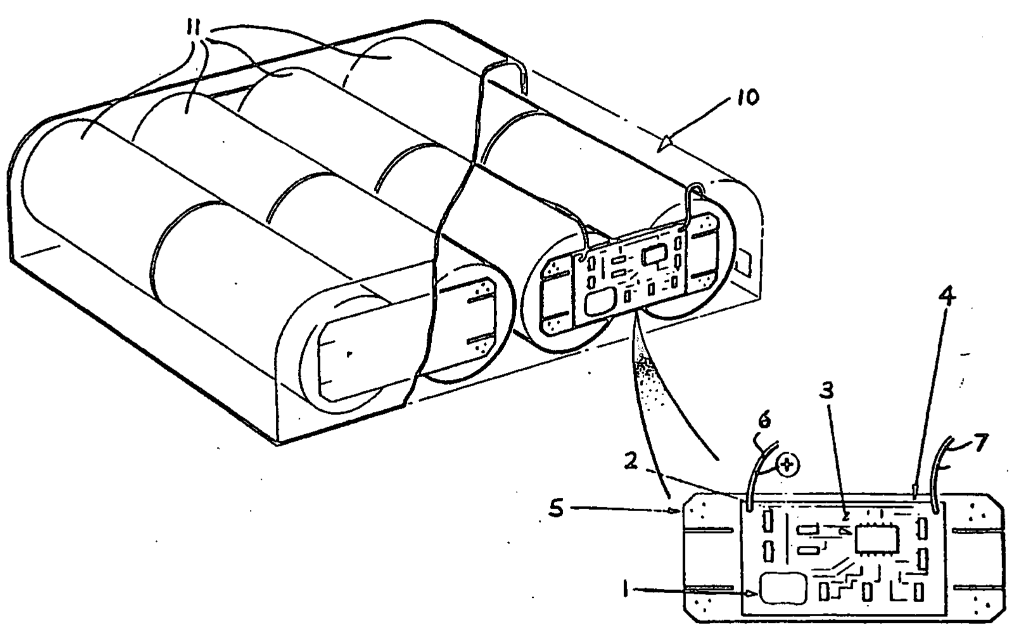

(57) Abstract

A battery monitoring device is formed on a conductive battery link (5) which has one or more insulating layers on it. A plurality of conductive tracks (3) are formed on the insulating layer (4) or layers to form a pattern which is connected to the conductive link at two or more points. One or more integrated circuit components (1, 2) are mounted on the insulating layer or layers or conductive tracks and connected to the conductive tracks to monitor the current passing through the conductive link and to provide an output indicative of battery parameters.

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INTEGRATED BATTERY MANAGEMENT SYSTEMS

The present invention relates to integrated battery management systems and, more particularly, to the provision of so-called "embedded intelligence" components in battery packs and especially rechargeable battery packs.

In recent years, the use has grown remarkably of secondary (rechargeable) batteries for powering portable and remote location products. Various electrochemical technologies are available for secondary batteries, the vast majority of which have been well understood for many years.

One of the aspects of battery performance that is widely accepted is that the battery condition, state-of-charge (SOC), and other parameters are difficult or impossible to measure directly, with good accuracy, consistency and reliability. This is because the actual status of a particular battery varies in a complex way dependent on the prevailing environmental conditions, the near and long term usage history, the means adopted for charging, and other factors. On the other hand, the manner in which (say) usage history affects battery status is well understood theoretically and similar understanding exists for most other factors affecting the status of a particular cell.

In almost all products that use secondary batteries, those batteries would, in fact, be dispensed with if possible. Other than providing the essential function of power supply, batteries are often the bulkiest, heaviest and most expensive part of the product and the part that requires the most frequent replacement. In many products, the batteries may be the only part that needs periodic maintenance of any kind, or replacement.

These factors combine to provide an increasing demand from the market for higher performance from batteries, reduced weight and volume for a given ampere-hour capacity, shorter recharging times, longer service lifetime and lower

purchase costs. Furthermore, many established battery technologies that are widely used are based on heavy metals that are thought to have damaging environmental effects when such batteries are disposed in an uncontrolled way at the end of their service life. There are thus also regulatory pressures, related to the damaging environmental effects, placing restraints and demands on the ways that batteries are used. These pressures contribute to the call for more efficient batteries that last longer; development of new battery technologies has principally been motivated by this, and some of the newer technologies require carefully controlled conditions of use to be successful.

A complementary approach to the development of new battery technologies is the use of intelligent monitoring systems associated with the batteries, so that the use can be closely controlled. The methods developed require the embedding in each cell pack of a small number of information processing components. These "embedded intelligence" (EI) components are used to compute a numerical model of the battery behaviour, that over time becomes closely matched to the actual characteristics of the cells, by an adaptive process. Information regarding the battery is made available externally by a simple data communications port, or directly via pack mounted displays, etc.

According to a first aspect of the present invention, there is provided battery monitoring device comprising:

a conductive battery link having disposed thereon one or more insulating layers;

a plurality of conductive tracks formed on the insulating layer or layers to form a pattern which is connected to the conductive link at two or more points; and,

one or more integrated circuit components mounted on the insulating layer or layers and connected to the conductive tracks to monitor the current passing through

the conductive link and to provide an output indicative of batt ry parameters.

According to a second aspect of the invention, an embedded intelligence (EI) device for a rechargeable battery comprises a controllable impedance, the value of which, during recharging, is monitored by a charging device, and means for controlling the value of the impedance in accordance with a computed state-of-charge of the battery.

The integrated circuit components can provide EI functions such as battery state of charge monitoring and the like and can be used therefore to control battery use and recharging of rechargeable battery packs fitted with such battery links.

The results that can be achieved with these methods are excellent. The information from the EI components can be accessed by externally connected loads so that the usage of the battery can be controlled in a fashion to make the best use of the battery stored energy.

Chargers can be directly controlled by the EI system in the fashion discussed subsequently, or by other strategies, so that an "optimal" charging regime is employed. The information from the EI system can be used to give an indication of the battery SOC to the user, obviating unplanned downtime and overdischarge conditions. A direct consequence is a longer battery service life, and improved utilisation of a given volume of active battery material. Other related approaches can be used, with similar results, and the methods are also in general applicable to primary cells, i.e. non-rechargeable cells.

A further refinement of the present invention is the provision of means for controlling the power flow into or out of the battery.

According to a further aspect of the present invention therefore, in an EI-equipped recharging system, there is provided means for switching the charging current to or

from the battery by an electronically controlled device in series with the battery.

Several problems are common to all solutions of the type that require EI parts to be placed within a battery pack. Foremost among these is the strategy used to fit the EI parts within a battery, as typically the number of battery packs produced incorporating EI parts will range from many tens of thousands to - potentially - tens of millions per annum. Indeed, in our experience, the manufacturing method used has the greater effect on the cost of the EI-equipped battery pack, and therefore directly on the market take-up, than the cost of the specific EI parts themselves. Secondly, it must be recognized that EI battery packs are uncommon and will remain so for several years. However, there is a significant investment in place in the form of battery chargers and similar hardware that will not fall due for replacement for many years. This second point means that it is a major advantage, with anticipated direct effect on market take-up, if EI battery packs can be arranged in the near term to work with charging equipment that is already in place, giving noticeably improved performance.

One example of a device according to the present invention will now be described with reference to the accompanying drawings, in which:-

Figure 1 is a diagrammatic representation of a battery pack and conductive battery link;

Figure 2 is a circuit diagram of the device;

Figure 3 is a more detailed view of the conductive link;

Figure 4 is flowchart of a calibration cycle associated with the device; and,

Figure 5 is a circuit diagram of the device including a charging current switch.

The device of the invention provides a solution to the probl m of the manufacturing method for EI d vices, and is an innovative approach that makes use of parts already

required in the battery pack for other purposes. It draws on processes established for high production numbers in other areas with similar environmental and cost constraints e.g. automotive systems.

The process we have adopted is illustrated primarily by reference to figure 1 and in connection with a battery pack 10 comprising plural cells 11. The EI components 1,2 are mounted on copper tracks or tracking layers 3 which are formed on polyimide, other polymer, or ceramic insulating layers 4. The tracking layers are etched, printed or deposited to form the interconnections needed between the nodes and pins of the various EI components and the external circuit, that is, the batteries and associated connectors to circuitry outside the battery pack. The insulating layers 4, which support the EI components and associated interconnective tracking and the EI electronic components, are bonded directly to a plated copper, cupro-nickel, copper-manganin or other cell link 5 which is similar to the links normally used between individual cells in normal battery packs.

In figure 1, wires 6,7 respectively are shown providing the positive power supply to the EI components, from further up the cell chain, and carrying the data output from the EI system, to external circuitry. However, in many cell pack designs it will be possible to utilise copper tracking directly printed, deposited or formed on the interior surfaces of the insulating cell pack housing for these purposes. Depending on the specific design of the cell pack, it may be preferable to mount all of the EI components on conducting surfaces or tracks so formed on the insulating cell pack housing.

An electrical circuit for the EI system is given in figure 2 and its components are numbered for consistency with the other figure. It may include its own battery 14, to power EI components in particular configurations, but may not be required in all systems.

The link is shown in more detail in figure 3. It is possible to control the resistance of the link by the size and placement of stampings 12 through the link 5 or by selection of the resistivity of the link itself. Such control of the link resistivity may be by direct selection of the link material or by addition or overprinting of other substances with definable resistance, including cross-linked polymer compounds, conductive inks and the like, that can be used to cause the resistance of the link to change in a predefined fashion according to the level of (say) battery current, battery temperature, or other quantity. In this fashion the resistance of the link can be caused to change in a non-linear fashion if desired. The link can then be made to offer a small but finite and well defined resistance to the current flowing through it, and by measuring the voltage developed across standard points 8,9 (see Figure 3) on the link, a direct measure of the cell pack current is available to the EI components. The current sensing system is indicated at 13 in figure 2.

The connections 8,9 are made directly without specific manufacturing steps as such, by providing voids in the insulating layers 4 so that relevant ones of the conducting tracks 3 can directly contact the link. In most circumstances, one end of the current sensing link also forms the ground connection for the power supply to the EI components. This means of directly providing the current sensing system is a major advantage of this construction method.

As the EI parts are "information processing" components, it is possible with simple additional procedures to use a calibration cycle during production.

The calibration cycle is illustrated in the flowchart figure 4 and requires that a known value or values of current be passed by an external system through the link 5, figure 1. The voltage level developed across the link is, under these conditions, recorded by the EI components, and is then used to calculate the precis parameters of the

parts of the EI system used to measure current. In this fashion, components with inherently precise values (precision components) are not required in the EI system, leading to a significant saving in production costs, particularly for the sensing link itself.

The link assemblies shown in figure 1 can be delivered in continuous reel form and may used in the final assembly stages of the cell pack in the normal manner, replacing the conventional links previously used. With care it is possible to utilise either EI link reels, or conventional reels, with minor changes only to the production machinery.

In figure 1 a number of devices 1,2 are shown comprising the complete EI system. This is the form that is most acceptable for near-term production, comprising a standard microcomputer device 1, and other active and passive devices for conditioning and processing analogue and digital physical signals that are offered to the microcomputer. However, in the medium term, for the best production efficacy, it will be beneficial to prepare a microcomputer-based or other ASIC (application specific integrated circuit) for the EI functions. Again, the specific nature of the semiconductors is unimportant, but the single EI-ASIC or device can then advantageously be mounted in a flip-chip or in similar fashion, to simplify the complexity of the insulating 4 and conducting layers 3 that must be applied to the sensing link 5.

In figures 1 and 2, communication from the EI system is shown to be via a single data link. This is considered to be of the most general usefulness, although the techniques discussed above could also be applied to give specific displays local to the individual battery pack, or to provide simple digital or analogue output of particular battery functions. In the general case of a single data communications output, the opportunity arises to make the EI battery compatible with the many temperature-limited "fast" chargers that charge batteries until a measurement of the battery temperature indicates that 100% state of

charge has been exceeded. This measurement is commonly made via a third external battery terminal, in addition to the positive and negative power leads, to which a thermistor embedded in the cell pack is connected. The third battery terminal is connected to the charger circuitry when charging is in progress, and fast charging is terminated when the thermistor resistance is measured to be outside a defined band. Normally, a negative temperature coefficient thermistor is used, so that a low value will cause fast charging to be terminated.

In the proposed EI system, an impedance controlled by the EI parts is inserted between the data terminal and the battery negative terminal (Z_1), or in series with the negative terminal (Z_2), as shown in figure 2. When say 100% SOC is computed by the EI system during charging, this impedance is modulated to a low level to instruct conventional fast chargers to terminate the fast charge levels of current. This mode of operation need not interfere with normal data transmission via the datalink, and it is possible for the EI system only to provide this form of operation when (a) fast charging currents have been detected, and (b) responses have not been received to traffic placed on the data link. The possibility also exists of a useful standby mode of operation in these circumstances, different from the normal steady or pulsed "float" currents used by conventional chargers to attempt to maintain batteries at 100% SOC when they are held in a charger for extended periods. Here the EI system can demand brief periods of fast charge current levels, as it computes the SOC decaying with time, thereby ensuring that 100% SOC is maintained, in a manner not possible with most conventional chargers.

In this fashion, a measure of the self discharge rate of the cells 11 can also be determined. As the 100% SOC point (at least for NiCd and NiMH cells, and in general for other ch mistries) is well defined by a particular and directly measurable voltage, the amount of charge that must

be injected to return the batteries 11 to 100% SOC can be quantitatively m asured following a period when the batteries are connected to a charger, but neither charging nor discharging currents are flowing. Provided that the duration of this idle period is known, an elementary calculation gives the self-discharge rate. For this calculation to be successful, the cell temperature must be stable over the idle period, or the variations of temperature must be recorded by the EI components, particularly for cells such as NiMH cells where the self-discharge rate can vary substantially with temperature. The voltage defining 100% SOC must also be corrected for temperature according to the profile appropriate for the particular cell chemistry. Ideally a measurement of self-discharge rate will be conducted over a substantial period of time (say 12 hours or longer). In the normal course of events with battery packs in consumer use, such periods are commonplace, but it is clear that any correction strategy based on this technique must be able to observe the battery behaviour accurately over such periods of time and have available sufficient resources in terms of memory to store such data over these time periods or longer.

A further advantage of the EI system when working with conventional chargers is that depleted NiCd cells - which may be very hot through recent heavy usage - can be immediately recharged. Such a situation is, for example, common with high performance cable-free power tools. In these circumstances, conventional temperature-limited fast chargers will not permit charging to commence until the cells have cooled to within a target temperature range, normally below 40°C. However, provided the cells are known to be depleted, charging of NiCd cells can commence immediately, charging of these cells being an endothermic, rather than exothermic, process. As the EI system can accurately compute cell SOC, the simple modulated-impedance signalling strategy described can b safely used to direct

conventional chargers to start fast charging immediately, removing a major source of delay and user annoyance.

While control of charging processes for batteries equipped with EI components is primarily via transmission of data from the battery, to the charger, and vice versa, or by manipulation of the impedance or other parameters of a battery data terminal by the EI components, it is possible for the EI components to control the power flow into the batteries 11 directly.

This requires the insertion of an electronically controlled switch (implemented in this example as a FET F) or other device in series with the cell string, as shown in figure 5. Where charging rates above those that can be safely accepted by the batteries are detected by the EI components, the switch F can be opened to control these rates via a pulse-width modulation (PWM) or other regime or interrupted completely. Under these circumstances, heat sinking must be provided for the switch F. This heat sinking can advantageously be implemented either as part of the conductive link 5, as seen in figure 1, or else by providing an expanded area of conductive tracking on the cell casework as one of the connections to switch F, or by other means. In this fashion, the EI components can automatically tailor the charging regime to be ideal for the specific condition of the battery. This facility also opens the possibility of the external charger components being extremely simple, and means that safe charging of (say) NiMH cells is possible with chargers designed for (say) NiCd cells.

An impedance Z_3 is included to provide the option of a soft switching action during the PWM process enacted by the EI components. This reduces the likelihood of a sudden disconnection of the cell string by the EI components causing disturbance to the charger, and reduces the probability of the EI switching action disturbing any loads that are supplied by the battery under charge-while-operating conditions.

The impedance Z_3 might be a cross-linked polymer (XLPE) device, to permit complete disconnection of the battery if necessary under prolonged abusive conditions. In these circumstances, the switch F would be opened, so that any charging currents would be diverted to the impedance Z_3. After a time dictated by the design of the XLPE device, the current flow will cause it to switch to a high impedance state, disconnecting the batteries from the charger. This phenomenon could also be used in conjunction with thermochromic inks printed on the XLPE surface to provide a visual indication of "fault" or "full charge", which might be particularly useful in EI equipped battery packs which do not otherwise have an on-pack display. In this connection, the surface of the XLPE device must be mounted so as to be visible through the battery pack casework.

Battery temperature may be sensed as indicated by input T in figure 5, but it is envisaged that the EI block itself will act to provide temperature sensing and therefore the indication in figure 5 is not indicative necessarily of an external sensor.

While the principal intent of the electronic switch F is to control the flow of energy into the battery during charging, it is possible to configure the switch F in such a fashion as to permit both charging, and discharging, currents to be controlled. This modification is useful where abusive discharge currents are expected. The EI system then has the ability to restrain discharge currents within limits which are acceptable, or optimal, for the battery, extending both operating time and service life.

All batteries have a finite service life, varying from one cycle for primary (non-rechargeable) cells to many hundreds or thousands of cycles for secondary (rechargeable) cells. In most applications, the EI system will be incorporated in a battery pack or assembly which is either disposed of, or recycled, at the end of the service life of the batteries. The EI system itself may then

either be scrapped or reused. It is possible to devise battery pack designs similar to that shown in figure 1 wherein secondary battery cells themselves can be replaced at a service site, a procedure which is common for many portable products with internal batteries. Indeed, a battery pack design is possible wherein the user can replace the cells.

In this connection it will be realised that it is possible to operate an EI system with primary cells, although any EI functions associated with charging would not be operative of course.

CLAIMS

1. A battery monitoring device comprising:

a conductive battery link (5) having disposed thereon one or more insulating layers;

a plurality of conductive tracks (3) formed on the insulating layer (4) or layers to form a pattern which is connected to the conductive link at two or more points; and,

one or more integrated circuit components (1,2) mounted on the insulating layer or layers or conductive tracks and connected to the conductive tracks to monitor the current passing through the conductive link and to provide an output indicative of battery parameters.

2. A device according to claim 1, wherein the one or more integrated circuit components (1,2) provide the EI function of battery state-of-charge monitoring and are used to control battery use and recharging of rechargeable battery packs (10) fitted with said battery links (5).

3. A device according to claim 1 or claim 2, applied to a primary cell.

4. A device according to claim 1 or claim 2, applied to a secondary cell (10).

5. An embedded intelligence (EI) device for a rechargeable battery (10), the device comprising a controllable impedance, the value of which, during recharging, is monitored by a charging device, and means for controlling the value of the impedance in accordance with a computed state-of-charge of the battery.

6. A device according to claim 5, further comprising means for switching a charging current to or from the battery (10).

7. A device according to claim 6, wherein the current switching means is an electronically controlled device (F) in series with the battery.

8. A device according to any of claims 1 to 7, wherein one or more of the conductive links has a non-linear or varying resistance characteristic.

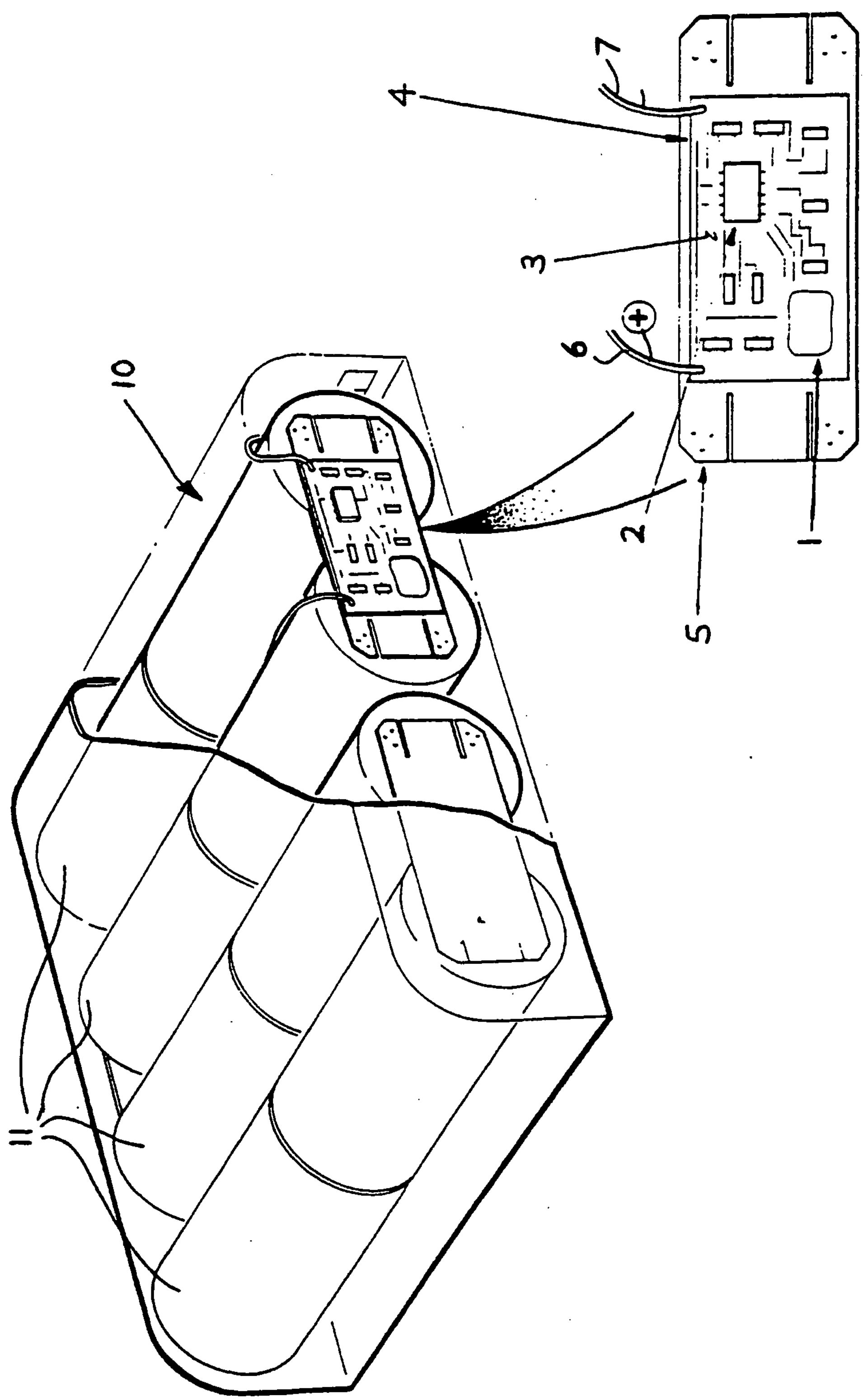

Figure 1:

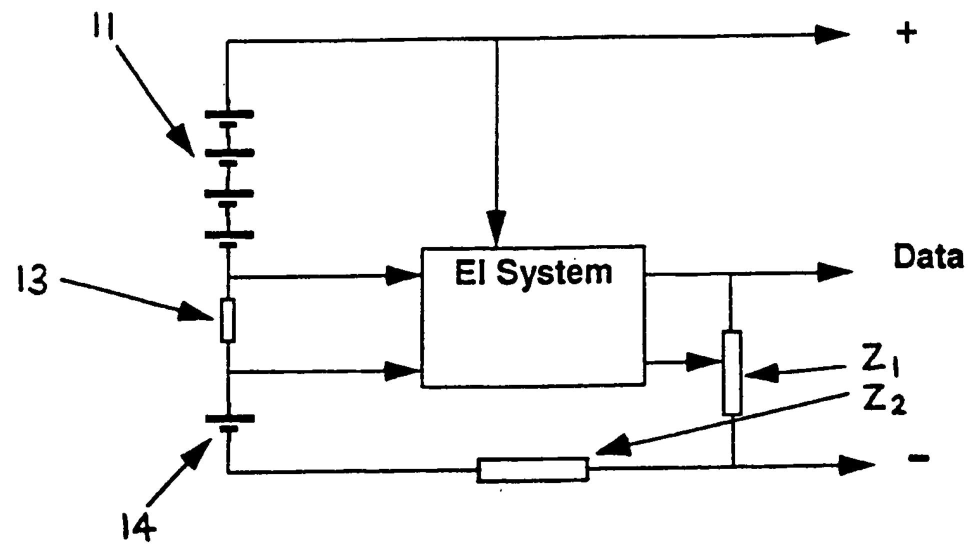

Figure 2

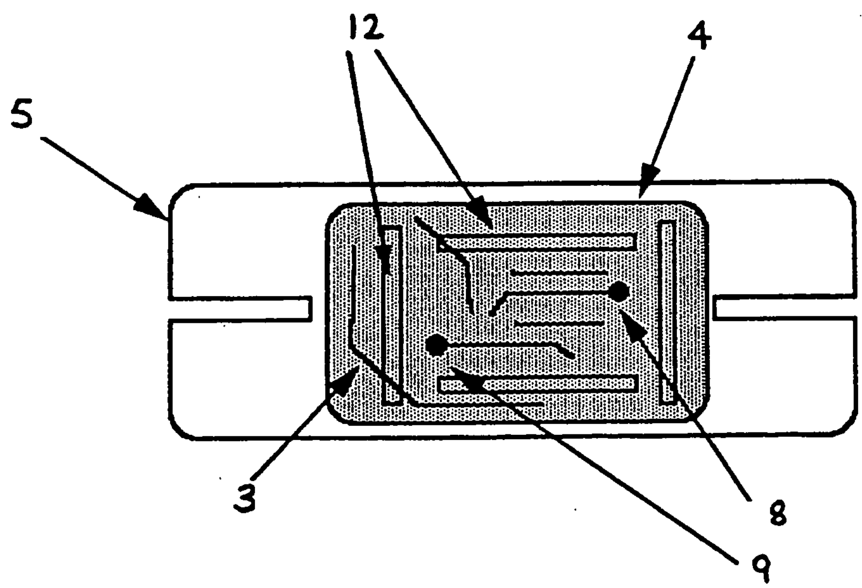

Figure 3

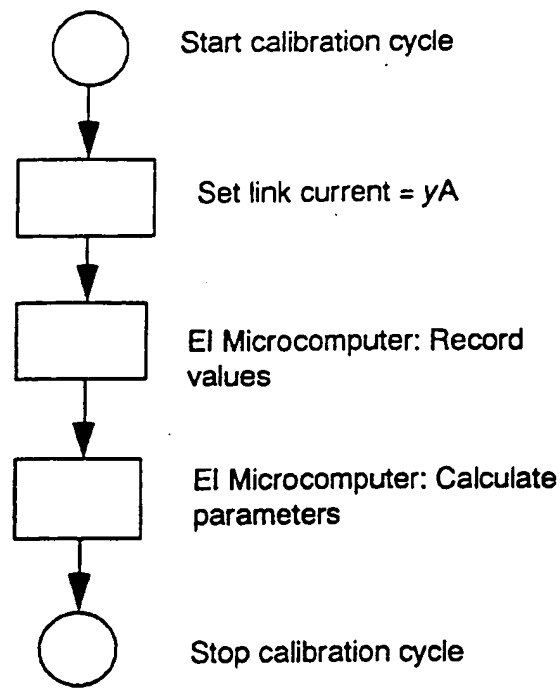

Figure 4

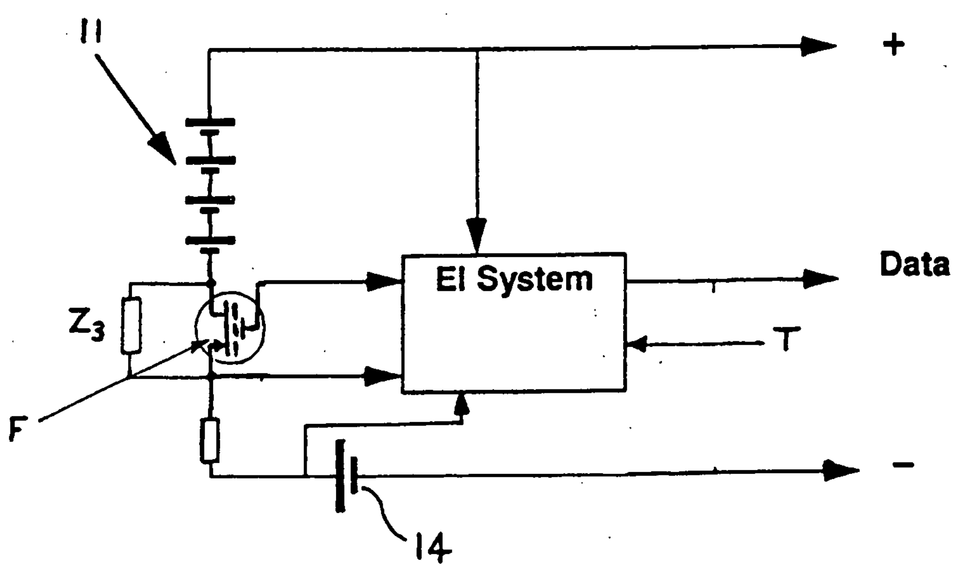

Figure 5

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 93/01361

A. CLASSIFICATION OF SUBJECT MATTER
IPC 5 H01M10/48 H02J7/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 5 H02J H01M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO,A,89 08940 (WIESSPEINER) 21 September 1989 see page 6, line 1 - page 16, line 25; figures 1-15	1,2,4,5
P,Y	EP,A,0 524 377 (VARTA) 27 January 1993 see column 2, line 37 - column 4, line 13; figures 1,2	1,2,4
Y	EP,A,0 480 648 (COMPAQ COMPUTER CORPORATION) 15 April 1992 see column 2, line 18 - column 10, line 46; figures 1-3	1,5
A	WO,A,90 02432 (FAIRGRIEVE) 8 March 1990 see page 5, line 1 - page 11, line 13; figures 1-11	1,2,4-7

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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